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Air Force Aerial Refueling Methods: Flying Boom versus Hose-and-Drogue

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Summary

Decisions on the composition of the Air Force aerial refueling fleet were made decades ago, when the primary mission was to refuel long-range strategic bombers. Modifications have been made to many of these tanker aircraft (KC-135s and KC-10s) to make them more effective in refueling fighter aircraft. This report, which will be updated, examines the balance between two different refueling methods in today's refueling fleet — “flying boom” and “hose-and-drogue.”

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Introduction

Air Force aerial refueling received considerable attention in the 108th and 109th Congresses. Much attention has focused on recapitalizing the KC-135 fleet, and a proposed — and ultimately rejected — lease of 100 Boeing KC-767 aircraft.¹ In light of proposed replacements to the tanker fleet, this report examines the Department of Defense's (DOD) mix of aerial refueling methods.

Currently, Air Force fixed-wing aircraft refuel with the “flying boom.” The boom is a rigid, telescoping tube that an operator on the tanker aircraft extends and inserts into a receptacle on the aircraft being refueled. (**Figure 1**).

Figure 1. USAF KC-10 Refueling B-52 with Flying Boom



Air Force helicopters, and all Navy and Marine Corps aircraft refuel using the “hose-and-drogue.” NATO countries and other allies also refuel with the hose-and-drogue. As its name implies, this refueling method employs a flexible hose that trails from the tanker aircraft. A drogue (a small windsock) at the end of the hose stabilizes it in flight, and provides a funnel for the aircraft being refueled, which inserts a probe into the hose. (**Figure 2**). All boom-equipped tankers (i.e., KC-135, KC-10), have a single boom and can refuel one aircraft at a time with this mechanism. Many tanker aircraft that employ

¹ See CRS Report RL32056. *The Air Force KC-767 Tanker Lease Proposal: Key Issues For Congress* for more information.

the hose-and-drogue system, can simultaneously employ two such mechanisms — and, refuel two aircraft simultaneously. The boom, however, can dispense fuel faster than a hose-and-drogue.

Figure 2. USMC KC-130 Refueling F/A-18s with Hose-and-Drogue



A single flying boom can transfer fuel at approximately 6,000 lbs per minute. A single hose-and-drogue can transfer between 1,500 and 2,000 lbs of fuel per minute. Unlike bombers and other large aircraft, however, fighter aircraft cannot *accept* fuel at the boom's maximum rate. (Today's fighter aircraft can accept fuel at 1,000 to 3,000 lbs per minute whether from the boom or from the hose-and-drogue.)² Thus, the flying boom's primary advantage over the hose-and-drogue system is lost when refueling fighter aircraft.

As decisions are made regarding the Air Force tanker fleet, an issue that may arise for Congress is whether to examine the mix of boom, and hose-and-drogue-refuelable aircraft in the Air Force. What might be the benefits and costs of any changes? Would DOD benefit in terms of increased combat power? If so, would this benefit justify the cost?

Background

Air Force aircraft have not always used the flying boom. All U.S. combat aircraft used the hose-and-drogue system until the late 1950s. The Air Force's decision to field boom-equipped tankers was based on the refueling needs of long-range bombers, which required large amounts of fuel. The Air Force's fighter community resisted eliminating the hose-and-drogue, but was overruled by the Strategic Air Command, which operated the tanker fleet, and during the Cold War, placed a higher value on refueling bombers.³

² KC-135 Aerial Refueling Manual T.O. 1-1C-1-3.

³ For more information on this history of air refueling, see [<http://www.centennialofflight>].

The perceived shortcomings of using a single boom to refuel fighter aircraft is reflected in a 1990 Air Force initiative to standardize DOD fighter aircraft refueling on the hose-and-drogue method. As initially conceived, the initiative consisted of three elements: (1) placing probes on all F-15 and F-16 fighters; (2) incorporating a probe in the design of the F-22A; and (3) adding two drogue pods to at least 150 KC-135s. To provide redundancy and flexibility, Air Force fighters would retain their boom receptacles.⁴ The 1991 war with Iraq (*Operation Desert Storm*) heightened DOD concerns over a lack of uniformity in aerial refueling methods. Navy leaders expressed frustration and dissatisfaction with the number of Air Force aerial refueling aircraft capable of employing the hose-and-drogue. Post-conflict analyses recommended that the Navy purchase its own fleet of land-based KC-10-sized tankers to increase the number of hose-and-drogue aircraft and reduce its reliance on Air Force aerial refueling.⁵

Navy concerns were mollified by Air Force promises of increased cooperation and undermined by a lack of budget to purchase new refueling aircraft.⁶ The Air Force's hose-and-drogue initiative was also scaled back. Instead of pursuing the three elements described above, the Air Force equipped 20 KC-135s and 20 KC-10s with Multi Point Refueling System (MPRS) kits that allow them to employ hose-and-drogue systems, either from wing pods, or attached to the end of the boom.

Effectiveness of the Current Air Force Fleet

The Air Force's aerial refueling fleet is often described as a "high demand/low density" (HD/LD) force. The fleet is in high demand because of the operational benefit derived from aerial refueling, the long distances U.S. combat aircraft often must fly, and the multiple operations in which they are engaged. Despite numbering well over 500 aircraft, the fleet is considered low density (few in number) for two apparent reasons.

First, the demand for hose-and-drogue refueling across DOD does not appear to be well matched by the Air Force's hose-and-drogue capabilities; this can create a refueling bottleneck. As some have observed, "Operation Desert Storm, Operation Allied Force in 1999 over Yugoslavia, and Operation Enduring Freedom in 2001 demonstrated that requests for fuel offload do not always match the capacity to deliver it."⁷ It appears that limited access to Air Force tankers has handicapped or complicated the Navy's long-range strike capability in some conflicts. Because KC-135 aircraft employ a single hose,

³ (...continued)

gov/essay/Evolution_of_Technology/refueling/Tech22.htm].

⁴ "Multipoint Refueling Planned for Air Force KC-135 Fleet," *Aerospace Daily*, Mar. 12, 1991, p. 420 and Government Accounting Office, Aerial Refueling Initiative: Cross-Service Analysis Needed to Determine Best Approach, GAO/NSIAD-93-186, July 1993, p. 7.

⁵ "Navy Sees Need for Organic Land-Based Tankers, More Satellites," *Aerospace Daily*, May 10, 1991.

⁶ "Navy/Air Force Deal Would Eliminate Navy Need for Large Tankers," *Aerospace Daily*, Sept. 25, 1991.

⁷ Hunter Keeter, "Naval Air Refueling Needs Deferred in Air Force Tanker Plan," *Sea Power*, Apr. 2004.

Navy fighters must cycle six to eight aircraft through the refueling queue. By the time the last aircraft has refueled, the first one requires more gas. This process can require three to four refueling hits for each aircraft before reaching a distant target. Navy and Marine Corps strike packages — often composed of 24 aircraft — have required as many as four KC-135s to meet their refueling needs.⁸ Suggesting a dearth of Air Force tanker support, U.S. Navy pilots who flew early missions against the Taliban during Operation Enduring Freedom described the UK Royal Air Force's (RAF) six VC-10 tankers that supported them as “a Godsend” and the “silent heros” of the air war. Navy pilots expressed a clear preference for RAF tankers over USAF tankers.⁹

To ameliorate a deficit in refueling assets during Operation Iraqi Freedom, the Navy flew refueling sorties with F/A-18E/F aircraft.¹⁰ While using the Super Hornet for aerial refueling demonstrated flexibility and reduced the Navy's dependence on the Air Force for refueling, these desirable attributes came at a cost. F/A-18E/F aircraft, and the pilots that fly them, are very specialized. Using these assets for aerial refueling rather than combat is seen as a sub-optimization of a scarce and valuable resource. F/A-18E/F squadron VFA-115 flew 623 sorties between March 21, 2003 and April 9, 2003: 216 were refueling sorties. When equipped to refuel other aircraft, Super Hornets carry only self defense weapons and are not equipped to conduct attack operations.¹¹

The second reason the 500+ aircraft tanker fleet is considered “low density” is that it does not appear that the flying boom's fuel transfer rate is fully taken advantage of, leading to an under-exploitation of the tanker fleet by most Air Force aircraft. In 2005, 96% of Air Force aircraft that are aerial refuelable use the flying boom. However, only 20% of the current Air Force fleet (669 bombers and surveillance aircraft of 3,227 aircraft) can use the refueling boom to its full capacity. Four percent of the Air Force fleet (139 helicopters of 3,227 aircraft) can't use the boom at all. Seventy four percent of the fleet (2,419 fighters of 3,227 aircraft) could potentially refuel with the hose-and-drogue with no reduction in fuel transfer rates.¹²

The following two scenarios illustrate the potentially more effective exploitation of aerial refueling assets by Air Force aircraft. If the Air Force were to replace its 1,356 F-16s and 356 A-10s (which are outfitted with boom receptacles) with 1,763 JSFs that are equipped to refuel with refueling probes, only 43% of the fleet (1,470 of 3,372 aircraft) would need to be refueled with booms. (The black and black-and-white columns in **Figure 3**). Air Force boom-refuelable aircraft would be evenly divided between large aircraft that can use this method at its full transfer rate and small aircraft that use the boom at a reduced transfer rate.

⁸ Ibid.

⁹ David Graves, “Britain's Flying Tankers Hailed as ‘Godsend,’” *London Daily Telegraph*, Nov. 10, 2001.

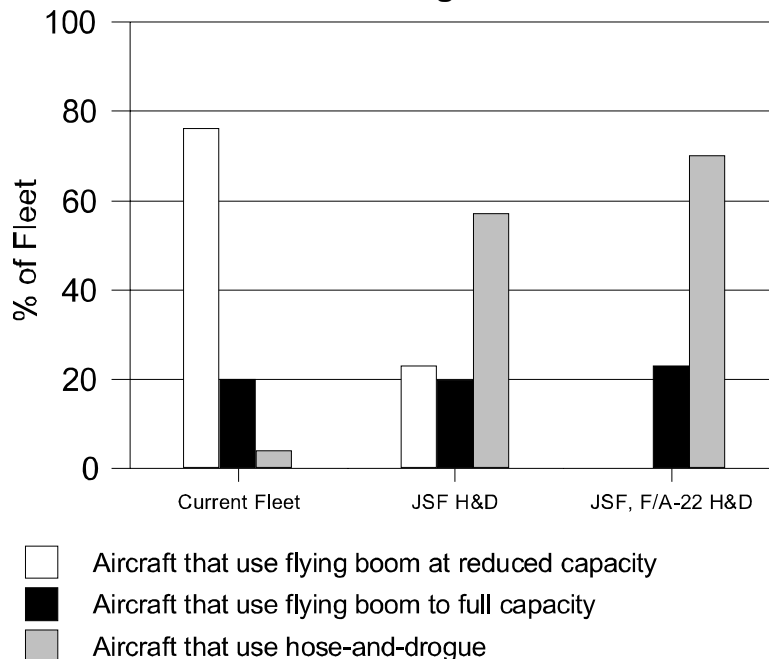
¹⁰ David Fulghum, “Tanker Puzzle,” *Aviation Week & Space Technology*, Apr. 14, 2003. P.23.

¹¹ USN Office of Legislative Affairs, telephone conversation with CRS, Apr. 13, 2004.

¹² *Refuelable Aircraft Inventory*, (Excel Spreadsheet) USAF Office of Legislative Liaison, Weapons Division, Apr. 12, 2005.

The Air Force wishes to replace its 722 F-15s, and 55 F-117s (777 total) with the F-22A Raptor. It too could potentially be modified to refuel with hose-and-drogue systems. Because the F-22 design is more mature than that of the JSF, changes to the aircraft to convert it from boom to hose-and-drogue refueling may be more expensive and potentially infeasible. The Air Force wants 381 Raptors. The current budget plan supports the purchase of 179 F-22As.¹³ If the Air Force were to modify the F-22A to refuel by the hose-and-drogue method and if the Air Force were to replace its 777 legacy aircraft with 381 Raptors, the percentage of the total fleet that would require boom refueling would drop to 23% (669 of 2,932 aircraft). All these aircraft use the boom at its full transfer rate. Seventy-seven percent of the fleet (2,243 of 2,912 aircraft) would use the hose-and-drogue refueling system and be interoperable with Navy, Marine Corps and allied refueling aircraft.¹⁴

Figure 3. Current and Hypothetical Air Force Aerial Refueling Profiles



Potential Issues

Considering changes to the mix of refueling methods in the Air Force tanker fleet appears to raise two overarching issues: potential operational benefit and potential cost. The primary potential operational benefit of increasing the number of aerial refueling hoses has already been described above: a more effective use of aerial refueling assets. Another potential benefit of increasing the number of aerial refueling hoses may include

¹³ See CRS Report RL31673, *F-22A Raptor*, by Christopher Bolkcom.

¹⁴ This analysis assumes no changes to other aircraft in the Air Force fleet. If the number of long-range bombers, strategic airlift aircraft, and aerial refueling aircraft (capable of being refueled themselves), increases in the future, the percentage of aircraft most in need of boom refueling would also increase.

greater interoperability and thus more effective coordination among the Air Force, Navy, Marine Corps, and allied air forces.

Calculating the potential costs of increasing the proportion of hoses to booms in the Air Force tanker fleet would depend in large part on how DOD and Congress might decide to recapitalize and upgrade the current fleet. One option would be to replace the oldest KC-135s with new aircraft equipped with two refueling hoses. Structural modifications to commercial aircraft to accommodate a flying boom are more significant than the modifications for hose-and-drogue mechanisms. The boom itself also costs more than the hose-and-drogue and is more complex. Thus, these new aircraft would likely be less costly than new, boom-equipped tankers. Newer KC-135s and KC-10s with booms would need to be retained to refuel large aircraft.

Another option would be to replace the oldest KC-135s with new, boom-equipped tankers and to outfit the remaining tankers with the Multipoint Refueling System (MPRS). Estimates by the GAO and CRS suggest that the cost of producing and installing the MPRS could be roughly \$5.1 million per aircraft in 2004 dollars or \$510 million for 100 aircraft. (Air Force program officials estimate it takes approximately 7,000 man-hours, or up to seven months, to modify KC-135s to accept the MPRS.)¹⁵ This cost estimate does not consider newer systems being developed that could be more or less expensive than MPRS.¹⁶

Regardless of which approach is taken to recapitalize the KC-135 fleet, legacy USAF fighter aircraft would need to be retrofitted, and new aircraft would need to be manufactured with refueling probes if they were to exploit multipoint hose-and-drogue refueling. It may be that the costs incurred by these modifications could be offset by the cost savings derived from improved aerial refueling effectiveness and corresponding reductions in tanker force structure. “According to 1991 Air Force estimates, the \$1.3 billion cost to modify about 3,000 F-15 and F-16 fighter and 250 tankers [to hose-and-drogue configuration] could be offset by reduced operating and support costs from the retirement of about 26 KC-135 tankers.”¹⁷

At least five studies have examined the pros and cons of a single boom versus multipoint hose-and-drogues.¹⁸ Because these studies considered different operational

¹⁵ Michael Gething, “KC-135 Upgrades Continue Apace,” *International Defense Review*, May 14, 1999.

¹⁶ GAO/NSIAD-96-160, estimated that the Air Force would spend \$204 million to equip 45 KC-135s with MPRS. On January 27, 1997, Boeing received a \$23 million contract to fabricate nine kits to convert nine KC-135Rs to the MPRS configuration. On December 20, 1997, Boeing was awarded a \$15.5 million “face value increase” to the MPRS contract. \$38.5 million / 9 MPRS kits = \$4.2 million per MPRS in 1997 dollars. To account for inflation, a DOD deflator of 1.2156 was used. $1.2156 \times \$4.2 \text{ million} = \5.1 million in 2004 dollars. On July 1, 1996, the Air Force awarded a contract to Boeing for \$8.7 million for two MPRS ship-sets. Using the same deflator to account for inflation, this equates to \$5.3 million per MPRS ship-set in FY2004 dollars.

¹⁷ GAO/NSIAD-93-186, op. cit.

¹⁸ Enhancing USAF Aerial Refueling Capabilities, RAND, 1990; *Utility of KC-135* (continued...)

factors in their analyses and made different assumptions, they came to different conclusions. However, all found that tankers equipped with multipoint hose-and-drogue refueling would refuel combat aircraft more effectively than boom equipped aircraft and could therefore allow a reduction in the tanker fleet. Reduction estimates ranged from 17% to 50%.¹⁹ These reductions would result from the increased speed with which a multipoint hose-and-drogue-equipped aircraft could refuel multiple-aircraft strike packages. The following evaluation illustrates how increasing the speed with which combat aircraft are refueled could translate into increased efficiency and potentially lead to reduced tanker force structure and cost savings:

by refueling two fighters simultaneously, the time that the fighters spend refueling can be reduced by approximately 75 percent. This reduced refueling time, in turn, would enable the tanker to have considerably more fuel available to off-load to other receivers....The less fuel burned by either the tanker or the receivers during aerial contact, the more that is available to conduct the fighter mission. At fighter refueling speeds, a KC-135A burns something in excess of 200 pounds per minute. Reducing the air refueling time from 40 minutes to 10 minutes (75 percent) makes approximately 6,000 pounds of additional fuel available....the fuel savings in a four-tanker formation could be enough to refuel an extra flight of four fighters or allow the same mission to be accomplished with one less tanker.²⁰

Advocates of the flying boom argue that it is prudent to maintain a large number of these tankers in the Air Force. While fighter aircraft receive much media attention, the contribution of long-range bombers to recent conflicts has been noteworthy.²¹ These aircraft may become even more important as the United States reduces its overseas basing and deploys over greater distances. Bombers and other large aircraft can spend as much as 20 minutes refueling at the boom's maximum capacity. Refueling such aircraft with the hose-and-drogue is infeasible.²²

Further, boom advocates argue, technological advances are being made in new booms which reduce operator workload and should make them safer and more reliable than the hose-and-drogue method.²³ Industry is incorporating commercial, off-the-shelf technology in booms currently under development, hoping to make them "fail safe."²⁴

¹⁸ (...continued)

Multipoint Modifications, AFSAA, 1992; *Impact of Multipoint/Receptacle Modifications*, AMC/XPY, 1993; *Aerial Refueling Initiative*, GAO, 1993; *Multipoint Refueling Program Cost Benefit Analysis*, Frontier Technology, 1995.

¹⁹ Paul Killingsworth. *Multipoint Aerial Refueling: A Review and Assessment*. RAND, 1996, pp. vii-ix.

²⁰ Maj. Marck R. Cobb, "Aerial Refueling: The Need for a Multipoint, Dual-System Capability," AU-ARI-CP-87-3, Air University Press, July 1987.

²¹ See CRS Report RL31544, *Long-Range Bombers: Background and Issues for Congress*.

²² CRS interviews with Air Force aerial refueling personnel, Sept. 2004 - Mar. 2005.

²³ See, for example, David A. Fulghum, "Lowering the Boom," *Aviation Week & Space Technology*, Feb. 7, 2005.

²⁴ Lisa Troshinsky, "EADS' aerial refueling boom to be lightweight, fail-safe," *Aerospace* (continued...)

Finally, it is argued, tankers with flying booms are in some ways more flexible than tankers with hose-and-drogue refueling. A tanker with a flying boom can be converted in the field to accommodate probe-equipped aircraft, if necessary. Hose-and-drogue tankers cannot be converted to accommodate aircraft with boom receptacles. To accommodate fighter aircraft, tankers with flying booms can reduce the speed at which they dispense fuel.²⁵ Tankers with hose-and-drogue refueling cannot increase the speed at which they dispense fuel to accommodate bombers and other large aircraft.

²⁴ (...continued)

Daily and Defense Report, Sept. 15, 2004

²⁵ KC-135 Aerial Refueling Manual T.O. 1-1C-1-3.